$\Upsilon(nS) \rightarrow \Upsilon(1S)\pi^+\pi^-$ at Belle

2006 June, QWG2006 WS at BNL
Kenkichi Miyabayashi
Nara Women’s University
(for Belle collaboration)

All numbers/plots are still preliminary.
Introduction

Below charmed (or bottomed) meson pair threshold, $V' \rightarrow V \pi \pi$ transitions can commonly take place, where $V'$ and $V$ are vector quarkonium, for example $\psi(2S) \rightarrow J/\psi \pi\pi$.

Recently, even above $D$ meson pair threshold, $V' \rightarrow V \pi \pi$ can happen. See BES, CLEO result, $\psi(3770) \rightarrow J/\psi \pi\pi$, PLB605(2005)63, PRL96(2006)082004

How about $\Upsilon$ case?
$\rightarrow$ B-factories must be capable to answer!
Hadronic Event Selection

Used data: $\Upsilon(4S)$ On + Off resonance($\sim10\%$) 477fb$^{-1}$.

- Number of charged tracks $\geq 3$
- At least 2 clusters in Electromagnetic Calorimeter (ECL)
- $E_{\text{vis}} \geq 0.2\sqrt{s}$, here $E_{\text{vis}}$ obtained by both charged and neutral particles.
- $0.18\sqrt{s} \leq E_{\text{ECL}} \leq 0.8\sqrt{s}$ to suppress (Radiative) Bhabha.
($\Upsilon(1S) \rightarrow e^+e^-$ is rejected here, only $\Upsilon(1S) \rightarrow \mu^+\mu^-$ is used.)
Further selection to have
\[ e^+e^- \rightarrow \mu^+\mu^-\pi^+\pi^-X \]

- Tighter requirement; \( 10.5\text{GeV} < E_{\text{vis}} < 12.5\text{GeV} \).

- Invariant mass of oppositely a charged track pair > 9GeV.

- \( \mu \)-ID; \( \mu \)-likelihood > 0.8.

- Lepton identified tracks are removed from \( \pi^\pm \) candidates.
Two charged particles’ inv. mass

The two tracks’ invariant mass > 9 GeV.

Requiring existence of $\mu^+\mu^-\pi^+\pi^-$ eliminates most of background.
$M_{\mu\mu}$ spectrum in $\mu^+\mu^-\pi^+\pi^- X$

$\Upsilon(1S)$ appears as a prominent peak in $M_{\mu\mu}$ distribution.

Obtained mass is consistent with WA.
\[ \Delta M = M_{\mu\mu\pi\pi} - M_{\mu\mu} \]

Select \( \Upsilon(1S) \rightarrow \mu^+\mu^- \) candidates, see mass difference(\( \Delta M \)).

In \( \Delta M \) distribution, three peaks due to
\( \Upsilon(2S) \rightarrow \Upsilon(1S) \)
\( \Upsilon(3S) \rightarrow \Upsilon(1S) \)
and the third peak seems to be
\( \Upsilon(4S) \rightarrow \Upsilon(1S) \).
So, see further detail.
Is it radiative return? 
\((e^+e^- \rightarrow \gamma \, \Upsilon(1S), \gamma \rightarrow e^+e^-?)\)

When misidentify \(\gamma \rightarrow e^+e^-\) as \(\pi^+\pi^-\), opening angle is small \(\rightarrow \cos\theta_{\pi\pi} \sim 1\)

\(\Upsilon(3S) \rightarrow \Upsilon(1S)\)

\(\Upsilon(2S) \rightarrow \Upsilon(1S)\)

Little background in \(\Upsilon(3S) \rightarrow \Upsilon(1S)\) and \(\Upsilon(2S) \rightarrow \Upsilon(1S)\) cases!
In order to check further detail in $\Delta M$ distribution of this peak, $\cos\theta_{\pi\pi} < 0.95$ is applied.
ΔM; detailed look

Obtained 1st and 2nd peaks are consistent with Υ(2S), Υ(3S) → Υ(1S)
ΔM; detailed look at 3rd peak

3rd peak is found to be consistent with $\Upsilon(4S) \rightarrow \Upsilon(1S)\pi^+\pi^-$, with statistical significance of 8.5σ!

$$\text{Br}(\Upsilon(4S) \rightarrow \Upsilon(1S)\pi^+\pi^-) = (1.1 \pm 0.2\text{(stat)} \pm 0.1\text{(sys)}) \times 10^{-4}$$

$$\Gamma(\Upsilon(4S) \rightarrow \Upsilon(1S)\pi^+\pi^-) = 2.2 \pm 0.6\text{(stat)} \pm 0.2\text{(sys)} \text{ keV.}$$

(same order as other $\Upsilon(nS) \rightarrow \Upsilon(1S)\pi^+\pi^-$ width.)
Off resonance data (60 MeV lower)

Consistent with expected background.
M_{\pi\pi} distributions

\( \Upsilon(2S) \) and \( \Upsilon(3S) \rightarrow \Upsilon(1S) \pi^+\pi^- \) are well described by Brown-Cahn and Moxhay models. \( \rightarrow \) consistent with CLEO measurement (PRD58 052004, PRD49 40).
$\mathbf{M_{\pi\pi}}$ distributions (cont.)

$\Upsilon(4S) \rightarrow \Upsilon(1S)\pi^+\pi^-$ is consistent with Brown-Cahn model.

$\Upsilon(4S) \rightarrow \Upsilon(1S)$ is consistent with Brown-Cahn model.
Summary and prospect

Belle studies transitions between $\Upsilon$ states.

• $\text{Br}(\Upsilon(4S)\rightarrow\Upsilon(1S)\pi^+\pi^-) = (1.1\pm0.2\text{(stat)}\pm0.4\text{(sys)}) \times 10^{-4}$
• $\Gamma(\Upsilon(4S)\rightarrow\Upsilon(1S)\pi^+\pi^-) = 2.2\pm0.6\text{ (stat)}\pm0.2\text{(sys)}$ keV.
• $\Gamma(\Upsilon(3S)\rightarrow\Upsilon(1S)\pi^+\pi^-) = 1.2\pm0.2$ keV.
• $\Gamma(\Upsilon(2S)\rightarrow\Upsilon(1S)\pi^+\pi^-) = 8.1\pm1.2$ keV.

Prospect

• Continue to accumulate more $\Upsilon(4S)$; other transitions’ signature would appear.
• Plan to take/analyze data at other energies($\Upsilon(5S)$, $\Upsilon(3S)$), there would be also some opportunities to see other transitions between $\Upsilon$ states.
Back up slides
$\cos\theta_{\pi\pi}$ for B.G.
$M_{\pi\pi}$ for B.G.

![Graph showing $M_{\pi\pi}$ distribution with entries per $80$ MeV/c$^2$, $bkg.$, and arrows indicating $1st$ & $2nd$, $2nd$, and $3rd$ peaks.](image)